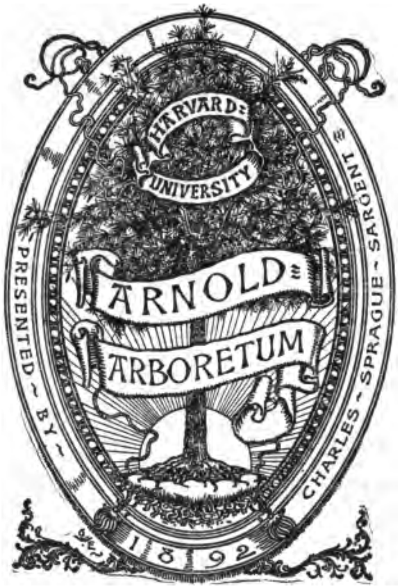
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ON THE

ADVANTAGES OF UNDERPLANTING

THE

LIGHT-DEMANDING, THINLY-FOLIAGED SPECIES

OF

FOREST TREES.

BY

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One of the most important principles of sylviculture is the conservation of the productive capacity of the soil, and it is only when measures are carried out in that direction that a permanent sustained yield of the best classes of timber is possible. The first step towards the practical attainment of this object is undoubtedly the protection of the soil against insolation by means of a leafy canopy giving shade, and also against the drying action of winds by means of a covering of dead leaves and *humus* or vegetable mould. Certain thickly-foliaged forest trees, like the beech, spruce, Douglas, Nordmann's, and silver firs, are naturally endowed with the requisite soil-protective qualities throughout their whole period of development until maturity. But many of our most valuable species, like oak, ash, maple, birch, larch, and pine, lose their power of protecting the soil at a comparatively early age, long before they attain their normal maturity as forest crops; and in consequence of the interruption that takes place in their canopy, the effects of insolation and of the action of wind and rain on the soil tend to weaken its productive power, and, if unchecked, ultimately lead to its deterioration sooner or later.

To counteract the natural consequences of early interruption of canopy due to increased individual demands for light and growing-space, the best means at hand consist in the under-planting of forests of light-demanding trees with other species

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content with less supplies of light, air, and warmth. Through the foliage of these the soil is kept cool and moist, whilst a good layer of vegetable mould is further provided for the enrichment of the soil by the annual defoliation of the leaves or needles; the direct influence of this measure makes itself apparent in the more annual rapid increment on the standards.

In the naturally open forests of oak, for example, there is usually some spontaneous undergrowth; but when this consists of brushwood or scrub its beneficial influence is by no means so marked as in the case of artificially-formed underwood consisting of beech or hornbeam. The first recorded occasion on which underplanting of oaks was carried out for the express purpose of "*giving a covering of fallen leaves to a soil already* " *overgrown with whortleberry, and thus strengthening its* " *productive capacity and stimulating the diminished incre-* " *ment of the oaks,*" took place in the Spessart Forest in Central Germany about 1840,* but since then the practical advantages of such a measure have not failed of recognition, as it leads to considerable financial improvement in the further development of the standards.

There are, however, two distinct methods in which the measure can practically be carried out. The undergrowth may have solely the object of temporarily retaining or improving the productive capacity of the soil; or it may be formed with the intention of allowing it to grow up and ultimately form a portion of the crop which is to be harvested in its full maturity at the end of the period of rotation. In the latter case it also affords the sylviculturist the opportunity of forming mixed instead of pure forests for the succeeding crop, and thereby obtaining a class of forest which certainly needs more attention in the way of tending, but has many solid advantages over pure forests in yielding larger crops of greater technical value, and in comparative immunity from the attacks of insect enemies and of fungoid diseases.†

But although the practical advantages of underplanting should have been apparent to all, there were not wanting those who condemned the measure on the ground that the undergrowth consumed the nutriment available in the soil in place of stimulating the standards to enhanced increment, whilst at the same time it often entailed considerable outlay.‡ These objections

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* See "*Monatschrift für Jagd-und Forstwesen,*" 1874, page 1.

† See essay "*On Mixed Forests, and their Advantages over Pure Forests,*" pages 5–18.

‡ See Borggreve in "*Forstliche Blätter,*" 1877, page 220, and 1883, page 41.

have, however, fortunately brought the matter under the notice of the experimental section of the Forest Branch of the Faculty of Economic Science in Munich University, and in the following pages a short resumé will be given of the results of the investigations made, and the practical deductions drawn from the observations recorded.

Objections raised by Opponents of Underplanting.

The experiments on which the opponents of underplanting based their objections were of three classes :—

I. Experiments made with standards over coppice.

II. Observations recording the rate of growth in forests that had been underplanted for some time, and comparison with the rate of growth in other portions of the same timber crops that had not been underplanted.

III. Clearance of underwood in forests that had been underplanted, and comparison of the increment of the standards in the following year with that of those growing over underwood.

Borggreve maintained as regards I. that the increase attained in the breadth of the annual rings was only apparent up till the fifth year, whilst after that a decrease in the breadth was noticeable as soon as the underwood began to form canopy, and that the decrease became more marked with the increasing density of the canopy. He contended that the initially-enhanced increment was due to the diminution in the number of individual plants enjoying insolation and utilising the nutriment of the soil, and had nothing to do with the quicker decomposition of the dead foliage; he even maintained that the formation of *humus* or vegetable mould was interfered with by the full exposure to sun and wind, and to the extremes of moisture and temperature, which hindered the normal development of fungoid growth. As, however, the degree of insolation of the standards could not be affected by the removal of the coppice growth, the enhanced increment during the following five years must have been due to the more rapid formation of humus, and consequently to larger supplies of nutrient salts in the soil in a soluble condition, resulting from the decomposition of the layer of fallen leaves; for during the first few years, when the stool-shoots show their most energetic growth, they make *at least* as high demands on the nutrients in the soil as they do later on when forming close

canopy. As coppice shoots flush at once in the first year, his assertions about the production of humus being interfered with have no value; for the young shoots protect the leaves from being blown about, and act in the direction of modifying the extremes of moisture and temperature, thus favouring the normal process of decomposition. That the enhanced increment of the standards decreases about the fifth year merely shows that the extra supplies of nutrient salts, afforded by the richer decomposition of humus after the periodical cutting back of the coppice, become exhausted after between four to five years. An additional objection to these experiments is that the observations were only made at the lower end of the stem in place of all along the bole; for experiments made by Weise on oak standards show that after each clearance of coppice there is an enhanced increment on the lower portion of the stem mostly, but that towards the end of the period of rotation of the coppice, after the twentieth year of undergrowth, the increment near the base of the stem decreases, whilst it becomes enhanced further up the bole, thus leading to a nearer approach to the cylindrical form and to higher general technical and financial value of the timber.

Under II. and III. the following results of experiments were quoted:—

Experiment.	Class of Forest.	No. of Stems per Acre.	Diameter of Average Stem.	Height of Average Stem.	Cubic Feet per Acre.
			Ins.	Ft.	
No. 1	64-year-old Scots pine forest without underwood.	224	10·4	61·6	3,497
	64-year-old Scots pine forest with spruce underwood.	216	9·6	59·6	2,895
No. 2	42-year-old Scots pine forest without underwood.	494	6·1	44·0	2,050
	42-year-old Scots pine forest with spruce underwood.	453	5·1	36·6	1,090

These data were found to be far from conclusive, as the reliability of the former was materially shaken when the latter case was found to be a mixed forest of equal-aged pine and spruce (probably raised from sowing), where the struggle between the two species had been so keen as to affect the development of the pine, which only began to show good annual

increment after the spruce had been so interfered with in development as to necessitate their being thinned out, whilst in the portion shown as "with spruce underwood" the struggle was still going on, and the predominating pines suffered in consequence a partial loss of the annual increment they might otherwise have shown under normal conditions.

Measurements made by Zetsche in a 48-year-old Scots pine forest growing on sand, and underplanted with spruce 8 feet high, gave the following results:—

48-year-old Pine Forest.	Diameter of Average Stem.	Height of Average Stem.	Cubic Feet per Acre.	Total Basal Area of Stems.	Increment of Basal Area of Stems in the three years.			
	Ins.	Ft.		Sq. ft.		Sq. ft.		Sq. ft.
With spruce underwood	6·2	50·0	2,709	986·4	1875-77 .	=86·76	1878-80 . .	= 82·08
Without underwood .	6·2	50·3	2,809	1,015·2	Previous to clearance of underwood in 1877.	=93·96	After clearance of underwood in 1877.	=117·36

A subsequent revision of the experimental areas three years later (in 1883) confirmed the original data;* but as the areas only amounted to 0·225, 0·3, and 0·625 acres respectively, importance can hardly be attached to them as representing the natural state of affairs on a larger scale. As the mean average height of a plantation gives† a very sound means of judging of the quality of the soil, it appears evident that on the areas not underplanted the soil was somewhat better than on the other localities.

Observations made by Michaelis‡ in an oak forest with an 18-year-old undergrowth, chiefly of hornbeam and hazel in close canopy, showed that there was no practical difference between the annual increment on the standards there, and what was found on those in a different part of the same crop, which had been fenced off as a game-cover, and where the deer had browsed to such an extent on the shoots that there was practically no underwood. He noted, however, that the dead foliage was retained better, and was less liable to be blown away, on the part with undergrowth. That, in general, the productive power of soils can be retained without underplanting can hardly be safely argued from this one example, for in this particular case the relations of the soil as to moisture, exposure, &c., were not stated in detail.

* See "*Forstliche Blätter*," 1884, page 173.

† See Grebe's "*Betriebs-und Ertragsregelung*," 2nd edition, 1879, page 114.

‡ See "*Forstliche Blätter*," 1884, page 345.

Other observations were also made by him in 100 to 110-year-old pine forests, with beech undergrowth, and having a N.E. exposure; the following were the results he obtained:—

Scots Pine, 100 to 110 Years old.	Last 5 Years.	Last 6 to 10 Years.	Last 11 to 15 Years.
	Inches.	Inches.	Inches.
With undergrowth - -	0·296	0·292	0·400
Without undergrowth - -	0·316	0·356	0·400

The measurements were made by means of Pressler's "increment gauge," but it is not stated that all the spills of wood used for the countings were taken from that part of the stem which represented the true average annual increment of the stems. Few stems are cylindrical; hence, unless all the stems be operated on with the borer in similar proportion to the true increment, the data are not reliable. To have ascertained the true average breadth of the rings four spills should have been extracted from each stem at an equal height N., E., S., and W., and the mean of their measurements taken; yet this was not done. There would, however, have still been a serious flaw in the data, namely, that the measurements should not have taken place at breast-height only, but also in the upper portion of the stem. Michaelis made further observations in respect to a small 110-year-old oak plantation in the open, which was part of a grazing-ground till it was underplanted with silver fir in 1859, without being previously thinned or partially cleared. The measurements were made on sections taken at 3⅛ feet above the ground and at the top of the bole, just below the crown, the mean being used for purposes of comparison. The breadth of the annual rings was, in comparison with what it had been in the six years previous to underplanting,—

For the 1st six years after underplanting, 1·14 times as much.
„ 2nd „ „ „ 1·52 „
„ 3rd „ „ „ 1·13 „
„ 4th „ „ „ 1·10 „

These results he sought to explain away by the fact that at the time of underplanting the young plantations were closed to grazing or mowing, whilst the dead foliage of the oaks (and later on of the silver fir in addition) was retained for the formation of humus in place of being blown away by strong winds. He further ascribed the gradual diminution in increment throughout the third and fourth periods of six years after underplanting to the large claims that the undergrowth began to make on the nutrients available in the soil, and maintained

that, although it still remained greater than before under-planting was carried out, this simply showed that the effects of grazing and exposure to the action of winds were more injurious than the removal of a portion of the soil-nutriment by the silver fir underwood. That oaks will thrive better in the open when the herbage is not removed from the soil seems extremely probable ; but there is nothing in the above record to show that the diminution in the increment is not due to the oaks beginning to form a somewhat closer canopy, and to demand thinning or partial clearing with a view to stimulating afresh their productive power.

This closes the brief for the opponents of underplanting, and the case may now be stated for those in favour of the method as a means of enhancing the productive capacity of the soil, and stimulating the standard trees to livelier growth and to the formation of broader annual rings of wood.

Arguments adduced by Advocates of Underplanting.

In 1886 Frömbling* published the results of measurements made on 160-year-old oaks growing on what was formerly grazing land, but which had been underplanted 35 years previously. In the case of three stems, which had been left close together without thinning, the breadth of the annual zones was at its minimum at the time of underplanting, but increased as the undergrowth formed canopy, and attained a breadth unequalled by any annual zones even during the previous 50 to 60 years, when the natural energy of growth of the trees was greatest. The other stems, which had been thinned or partially cleared, showed at first considerable increment in the breadth of the annual zones in consequence of the thinning out; this, however, fell off for three years, and then increased again when the underwood improved the soil by forming canopy and yielding humus by the decomposition of the dead leaves. The results of Frömbling's experiment were therefore diametrically at variance with those recorded by Michaelis, and were at the same time not open to any doubt as to possible differences in the quality and physical properties of the soil and situation.

More extensive observations were classified in the same journal by Runnebaum,† who recorded the measurements made on two areas under Scots pine, one of which was 120 years old and underplanted with beech, the other a 110-year-old crop without underwood, situated half a mile distant from the former. An examination of the soil showed only inconsiderable

* "*Zeitschrift für Forst-und Jagdwesen,*" 1886, page 632.

† " " " 1885, pages 156 *et seq.*

differences as to its mineral composition, but the thick humus layer in the underplanted area had nearly double the quantity of mineral nutrients that were traceable in the thinner layer of mould in the forest without undergrowth. The outturn from the two equal sample areas was as follows, the price being 3·8*d.* per cubic foot in the former case and only 2·7*d.* in the latter :—

A.—120-year-old Scots pine underplanted with beech = 14,280 cubic feet pine + 343 cubic feet beech = 229*l.* 2*s.* + 27*l.* 13*s.* = 256*l.* 15*s.*

B.—110-year-old Scots pine without underwood = 13,370 cubic feet pine = 149*l.* 2*s.*

The first thing to strike one here is that, although (in consequence of heavier thinning of A at the time of underplanting) the annual average increment on A was only 119 cubic feet, whilst on B it amounted to 121½ cubic feet, yet there was a considerably higher price (+ 1·1*d.* cubic foot) derived from the pine growing over underwood, in consequence of its being straighter and smoother, more cylindrical in bole, and having annual rings *with proportionally larger development of the summer zone,* which, as is well known, is much more durable in conifers than the more porous spring zone. Here we have a confirmation of Prof. R. Hartig's theory that the underwood, by keeping the soil moist and cold in early spring, prevents the premature awakening of vegetation; in consequence of this the cambial activity is delayed for about a fortnight at least towards the warmer season of the year, when, in consequence of the greater warmth, the energy of the assimilative process and the formation of woody-fibrous tissue with thick cell-walls are materially enhanced. The greater freedom from branches must, to be fair and impartial, not be ascribed to any influence exerted by the undergrowth. It was probably due to an admixture of beech with the pine at the time of forming the forest; it had no connection with the beech underwood that sprung up spontaneously about the 60th or 70th year, as the natural clearance of all the lower branches must have been completed by that time. Measurements showed that after the spontaneous growth of the underwood the difference in diameter-increment became marked and continuous, as under :—

Diameters.	At 50 years.	At 80 years.	At 100 years.
A - - -	8·4 inches	12·0 inches	13·6 inches.
B - - -	7·4 „	10·0 „	11·2 „
Difference -	1·0 inches	2·0 inches	2·4 inches.

One point in which the Munich experiments, immediately about to be recorded, are acknowledged to be unsatisfactory is that, although over 7,500 acres of high forest have been underplanted, forests without undergrowth, but otherwise absolutely similarly situated as to soil, situation, exposure, method of past treatment, &c., are wanting to form an absolutely accurate comparison. But in comparison with the above-mentioned experiments they have at any rate the advantage of having been made so as to take into account the increment in height; or in other words, that not merely the breadth of the annual rings, but also the superficial increment and the increment in cubic contents have been reckoned and chronicled,—and this is the only method which can yield truly reliable data.

Investigations made by the Forestry Branch of the Faculty of National Economy in Munich University, in order to ascertain the actual Effects of Underplanting.

First Series of Investigations.

The first series of experiments, or more correctly of investigations, was conducted in an 82-year-old oak forest (*Quercus pedunculata*) on deep, fresh, loamy sand, underplanted 28 years previously with beech, which had partly grown up into the crowns of the standards; the soil was covered with a dense layer of dead leaves and humus. The preliminary outturn from thinnings had not been recorded in any available form. A sample area showed the outturn per acre to be:—

Per Acre.	No. of Stems.	Basal Area.	Diameter of Average Stem.	Height of Average Stem.	Contents of Bole.	Contents of Branches.	Total Cubic Contents.
		Sq. ft.	Inches.	Feet.	Cub. ft.	Cub. ft.	Cub. ft.
Oak .	136	770	11·48	65	7,000	875	7,875
Beech .	2,960	273	1·48	28	—	—	—

The calculation of the cubic contents was made by means of two sample stems taken from each of the three girth classes formed by the standards. The oaks being 82 years old, and underplanted when 54 years old, the details on pages 12 and 13 were obtained by counting back, and by measurement of the annual rings included in the various periods of time.

No. of Sample Stem.	Total Height of Stem.	Height at which Crown began.	Height above Ground of the Sections examined.	Present Diameter (free of Bark) in Inches.	Periodical Diameter-Increment in Inches.					Periodical Superficial Increment in Square Feet.				
					Years before Under-planting.		Years after Underplanting.			Years before Under-planting.		Years after Underplanting.		
					20–10.	10–0.	0–10.	11–20.	21–30.	20–10.	10–0.	0–10.	11–20.	21–30.
1	Feet. 60·6	Feet. 26·6	Feet. 4·3	6·16	1·00	0·60	0·88	0·44	0·40	0·0374	0·0275	0·0473	0·0264	0·0288
			16·6	5·36	0·88	0·76	0·84	0·56	0·48	0·0242	0·0253	0·0363	0·0286	0·0275
			33·3	4·00	—	1·68	0·76	0·52	0·76	—	0·0231	0·0209	0·0176	0·0297
			39·6	3·20	—	—	0·76	0·64	0·72	—	—	0·0132	0·0165	0·0220
			46·2	1·88	—	—	—	0·52	0·80	—	—	—	0·0055	0·0143
					Periodic Increment in Cubic Feet -					0·4410	0·9275	1·2915	1·0115	1·2285
2	56·0	—	4·3	7·00	1·00	0·84	1·12	0·60	0·44	0·0385	0·0407	0·0660	0·0407	0·0330
			16·6	6·00	0·76	0·92	0·96	0·60	0·48	0·0231	0·0352	0·0473	0·0341	0·0319
			33·3	4·80	0·48	1·32	1·12	0·80	0·56	0·0044	0·0253	0·0363	0·0341	0·0275
			39·8	3·76	—	1·40	0·80	0·76	0·64	—	0·0143	0·0176	0·0231	0·0253
			6·2	2·68	—	—	0·80	0·76	0·64	—	—	—	0·0143	0·0165
					Periodic Increment in Cubic Feet -					0·7560	1·2950	1·8620	1·5085	1·3475
3	67·3	33·3	4·3	9·40	1·52	1·04	1·56	0·76	1·00	0·0770	0·0671	0·1023	0·0671	0·0968
			16·6	7·96	1·16	1·16	1·12	0·76	1·00	0·0440	0·0594	0·0704	0·0561	0·0814
			33·3	6·40	1·04	1·24	1·36	1·04	1·16	0·0154	0·0330	0·0550	0·0561	0·0737
			50·0	3·00	—	—	1·20	0·76	0·84	—	—	0·0121	0·0165	0·0242
					Periodic Increment in Cubic Feet -					1·6310	2·0615	3·0100	2·5310	3·6505

No. of Sample Stem.	Total Height of Stem.	Height at which Crown began.	Height above Ground of the Sections examined.	Present Diameter (free of Bark) in Inches.	Periodical Diameter-Increment in Inches.					Periodical Superficial Increment in Square Feet.				
					Years before Under-planting.		Years after Underplanting.			Years before Under-planting.		Years after Underplanting.		
					20–10.	10–0.	0–10.	11–20.	21–30.	20–10.	10–0.	0–10.	11–20.	21–30.
	Feet.	Feet.	Feet.											
4	68·6	—	4·3	9·40	0·76	0·88	0·80	0·52	0·40	0·0539	0·0693	0·0704	0·0495	0·0396
			16·6	8·44	0·72	0·80	0·76	0·56	0·40	0·0440	0·0550	0·0594	0·0473	0·0363
			33·3	6·00	0·92	0·96	0·64	0·48	0·40	0·0308	0·0429	0·0341	0·0286	0·0253
			50·0	3·60	—	1·20	0·88	0·64	0·44	—	0·0143	0·0209	0·0198	0·0165
			56·6	—	—	—	0·80	0·72	0·56	—	—	0·0110	0·0154	0·0121
					Periodic Increment in Cubic Feet -					1·7150	2·3135	2·3555	1·9495	1·5925
5	71·3	30·0	4·3	12·88	1·92	1·32	2·96	1·68	1·52	0·0990	0·0913	0·2728	0·1969	0·1981
			16·6	10·12	2·08	1·56	2·16	1·60	1·16	0·0638	0·0781	0·1518	0·1452	0·1199
			33·3	8·44	—	1·88	2·60	1·80	1·44	—	0·0396	0·1177	0·1243	0·1232
			50·0	4·60	—	—	1·64	1·40	1·44	—	—	0·0220	0·0418	0·0627
					Periodic Increment in Cubic Feet -					1·9285	2·6420	6·9860	6·5695	6·6325
6	75·0	—	4·3	13·48	1·52	1·36	2·36	2·04	1·84	0·0902	0·1012	0·2244	0·2420	0·2871
			16·6	11·44	1·52	1·28	2·16	1·68	1·56	0·0715	0·0792	0·1738	0·1694	0·1815
			33·3	8·08	1·04	1·68	1·68	1·60	1·56	0·0154	0·0495	0·0803	0·1045	0·1265
			50·0	4·56	—	—	0·96	1·12	1·24	—	—	0·0198	0·0363	0·0550
					Periodic Increment in Cubic Feet -					2·1385	3·0450	6·1720	7·0280	8·0535

Immediately before the underplanting took place a partial clearance or strong thinning was carried out, which, as is usual is such cases, of itself stimulated the trees to greater energy in the formation of broad annual rings, but in such a manner as to lower the form-factor, *i.e.*, to induce a tapering form of the bole, the rings being considerably broader near the base than further up near the top. After 10 years, however, when the underwood began to form close canopy, a not inconsiderable diminution of increment and of the breadth of the annual rings resulted near the base, which was succeeded in the following or third decade by a slight increase again in the case of four out of the six sample trees. But along with such diminished increment during the second decade, there was at the same time, in consequence of the underwood forming canopy, an unmistakable effort on the part of the standards to assimilate their mode of increment towards what it usually is when the trees stand in close canopy in place of being in free enjoyment of light and air, namely, a raising of the form-factor or improvement in the shape of the bole, due to the rings near the base of the stem being much narrower than those immediately under the crown and throughout the upper third of the bole, where indeed the breadth of the rings either remained almost constant or increased somewhat, as may be seen from an examination of the tabular record already given. It may be remarked, that if 10 or 20 years previously the crown had been deeper seated than it was at the time of making the experiments, the measurements would be valueless for the purposes of comparison, but from the appearance of the upper portion of the bole such had evidently not been the case.

These changes in the form-factor and improvements in the shape of the bole are more marked when one examines the data recorded as to the periodical superficial increment, for whilst, immediately after the strong thinning or partial clearance took place, at 33·3 feet it amounted to only 30 to 60 per cent. of that at breast-height, during the third decade it rose to 50 to 110 per cent. If the increment at breast-height alone be taken into consideration, one might occasionally come to results diametrically opposed to those yielded by a more accurate computation of the actual increment; *e.g.*, sample stem No. 3 shows diminution of increment at breast-height, whilst the total increment throughout the stem in the last decade is greater than immediately after the partial clearance in the proportion of 3·6505 cubic feet to 1·6310 cubic feet. This improvement in the form-factor, inconsiderable though it often may be, is due to diminished

assimilation of nutrients and production of constructive matter in the crown of the trees, in consequence of which smaller quantities of assimilated nourishment are conducted back to the lower portions of the stem and to the root-system; whilst at the same time the mechanical hindrance offered by the underwood to insolation, and the cold shade cast over the soil, militate against the extraction of such large supplies of nutrients being drawn from the soil as would be the case if the latter were warmed by insolation and the root-system were stimulated by a greater degree of warmth. The diminished productive capacity of the crowns of the smaller and average classes of standards is probably mainly due to the free enjoyment of light and air being interfered with as they expand, whilst in the larger girth classes it may be ascribable to the undergrowth beginning to mingle with the lower portion of the leaf-canopy of the standards, and thus interfering with the assimilative power of the lower foliage.

Second Series of Investigations.

That the above-suggested probable main causes are justified may be deduced from the following data obtained from two 105-year-old oak standards that, after having for at least 20 to 30 years stood with their crowns in the full enjoyment of light and air, were underplanted with beech, now about 40 years old, which, growing in close canopy, was already partially forcing its way up into the lower portions of the crowns of the oaks. The forest occupied a high situation and was unprotected towards west and south, where it bordered on arable land; the quality of soil was below the average, and the oak standards were scattered about singly or in small groups throughout the beech undergrowth. Apart from the influence ascribable to the slightly inferior quality of the soil, the boles of the oaks were short, owing to their formerly having had a large amount of growing-space, due probably to wide planting originally; and whereas records showed that the soil had formerly been overgrown with whortleberries, it now had a thick covering of fallen leaves and a good layer of humus. The underwood was formed during 1843 to 1847 by means of sowing beech-nuts; this was carried out immediately after a thinning, and was succeeded in 1853 to 1856 by a clearance of all diseased stems. The measurements made showed that about eight years after the undergrowth was formed the rate of increment sank considerably, after having increased (owing to the thinning

out) at the time of its formation; that the effects of these two heavy thinnings or partial clearances continued for about two decades to reduce the form-factor by causing larger annual increment near the butt-end than at the top of the bole; that during the third and fourth decades after the formation of the underwood the basal increment was lower in No. 1 and the same as previously in No. 2, whilst in both cases the increment in the upper portions of the trees was somewhat greater; finally, that during the fourth decade the superficial increment of the various sections, and the total increment in cubic contents, were practically about the double of what they were throughout the decade previous to the underplanting, which emphatically disposes of the argument that the growth of the standards is injuriously affected by the underwood consuming a large share of the nutrients contained in the soil. That the gradual improvement in the form-factor or shape of the bole was due to the beech underwood interfering with the activity of the most deeply-seated foliage is hardly open to reasonable doubt. The detailed measurements were as follows (see page 17), the oaks being 105 years old at the time of the investigations, and having been underplanted at 65 years of age :—

No. of Sample Stem.	Total Height of Stem.	Height at which Crown began.	Height above Ground of the Sections examined.	Present Diameter (free of Bark) in Inches.	Periodical Diameter-Increment in Inches.						Periodical Superficial Increment in Square Feet.					
					Years before Underplanting.		Years after Underplanting.				Years before Underplanting.		Years after Underplanting.			
					20–10	10–0.	0–10.	11–20.	21–30.	31–40.	20–10.	10–0.	0–10.	11–20.	21–30.	31–40.
1	Feet. 59·6	Feet. 31·3	Feet. 4·0	13·44	1·48	1·12	1·68	2·28	1·40	1·20	0·0858	0·0506	0·1403	0·2387	0·1738	0·1672
			17·3	8·80	1·44	0·96	1·28	1·24	1·00	0·76	0·0440	0·0418	0·0715	0·0858	0·0814	0·0693
			37·3	6·32	—	1·04	1·12	1·08	1·28	1·12	—	0·0165	0·0275	0·0358	0·0688	0·0693
					Periodical Increment in Cubic Feet						—	3·7485	5·1764	5·1870	5·2010	6·1880
2	60·6	25·3	4·0	13·08	1·88	0·96	1·36	1·52	1·36	1·20	0·1166	0·0748	0·1221	0·1595	0·1650	0·1617
			14·0	11·12	2·08	1·16	1·36	1·32	1·12	0·96	0·0935	0·0726	0·1084	0·1188	0·1166	0·1166
			24·0	9·40	1·88	1·36	1·20	1·20	1·24	1·20	0·0441	0·0572	0·0661	0·0825	0·1012	0·1144
			38·0	7·60	—	—	1·52	1·32	1·40	1·36	—	—	0·0441	0·0594	0·0836	0·1023
			44·0	3·12	—	—	—	0·80	0·88	0·84	—	—	—	0·0088	0·0176	0·0242
					Periodical Increment in Cubic Feet						—	2·1350	3·1710	3·9725	4·5150	4·8305

Third Series of Investigations.

A third experimental area was again selected in the Spessart Forest, in an 88-year-old oak wood raised from seed on old arable land, and the past history of which was accurately traceable. Throughout the earlier periods of development its growth was good, but about the fortieth year the soil became thickly overgrown with whortleberry, the increment diminished considerably, and the crop had anything but a promising appearance. Without any previous thinning, beech-nuts were sown out in 1840 for the purpose of forming an underwood, but in 1844 to 1847 a strong thinning or partial clearance took place along with underplanting. Light thinnings were made in 1852 to 1854, 1859, and 1873, and in 1887 a further thinning out of about 80 stems per acre took place, leaving from 280 to 320, or in round numbers about 300, per acre, which at the time of the experiment formed close canopy. The effect of the first thinning was only so slight an increase of energy in growth as hardly to make itself noticeable in the breadth of the annual rings, or to affect the shape and form-factor; but slight as it was, it remained traceable during the third and fourth decades in the predominant and dominant stems, whilst the weaker individuals that fell into the subdominant class showed gradual diminution of increment in consequence of their crowns becoming suppressed. In this case the detailed measurements were as follows (see page 19), the oak standards being 88 years old at the time of the investigations, and the thinning out and underplanting with beech having taken place when they were 46 years of age :—

No. of Sample Stem.	Total Height of Stem.	Height at which Crown began.	Height above Ground of the Sections examined.	Present Diameter (free of Bark) in Inches.	Periodical Diameter-Increment in Inches.					Periodical Superficial Increment in Square Feet.				
					Years before Under-planting.	Years after Underplanting.				Years before Under-planting.	Years after Underplanting.			
					10–0.	0–10.	11–20.	21–30.	31–40.	10–0.	0–10.	11–20.	21–30.	31–40.
1	Feet. 67·3	Feet. 43·3	Feet. 4·0	7·44	0·72	0·96	0·72	0·64	0·52	0·0330	0·0528	0·0462	0·0451	0·0341
			14·0	6·72	0·84	0·96	0·72	0·56	0·48	0·0308	0·0462	0·0407	0·0352	0·0330
			24·0	6·20	1·16	1·16	0·80	0·64	0·48	0·0308	0·0462	0·0396	0·0363	0·0308
			34·0	5·16	1·16	1·40	0·96	0·76	0·60	0·0099	0·0297	0·0330	0·0341	0·0308
			40·6	4·08	—	—	1·08	0·92	0·68	—	—	0·0209	0·0286	0·0264
					Periodical Increment in Cubic Feet -					0·8295	1·6940	1·5575	1·6660	1·5365
2	71·6	46·6	4·0	9·40	1·04	1·04	1·20	1·32	1·24	0·0253	0·0319	0·0473	0·0748	0·0704
			14·0	8·32	0·96	1·00	1·16	1·20	1·16	0·0396	0·0462	0·0583	0·0693	0·0715
			24·0	7·92	1·44	1·16	1·12	1·24	1·12	0·0352	0·0484	0·0605	0·0835	0·0891
			30·6	7·12	1·56	1·40	1·24	1·16	1·00	0·0462	0·0473	0·0682	0·0858	0·0913
			37·3	6·52	—	1·60	1·32	1·48	1·08	—	0·0572	0·0814	0·1067	0·1177
					Periodical Increment in Cubic Feet -					1·3055	1·8935	2·7160	3·9480	4·5135
3	74·0	53·3	4·0	9·56	1·36	1·16	1·12	0·96	0·88	0·0693	0·0759	0·0869	0·0847	0·0869
			14·0	8·16	1·36	1·12	0·96	0·92	0·80	0·0539	0·0550	0·0627	0·0682	0·0671
			20·6	7·80	1·96	1·48	1·04	0·88	0·88	0·0539	0·0682	0·0616	0·0616	0·0704
			27·3	7·20	—	2·12	1·16	0·88	0·92	—	0·0726	0·0605	0·0561	0·0660
			34·0	6·88	—	—	1·48	1·12	1·00	—	—	0·0638	0·0649	0·0693
			40·6	6·00	—	—	1·96	1·64	1·28	—	—	0·0451	0·0682	0·0748
					Periodical Increment in Cubic Feet -					1·5890	2·2855	2·8175	3·1780	3·8850

As regards increment in height, the analyses of the sample stems in the above experiments showed that this diminished after the strong thinning or partial clearance, but eventually regained its former level, and in some cases exceeded what it had previously been. So far as any deduction may be allowable from the comparatively small number of sample trees, it seems to be the case that after each thinning the diminution of increment in height was due to the tendency of the oak to expand laterally and internally to the prejudice of the vertical energy, which, however, regained its ascendancy when once the crowns again began to form close canopy.

Such are a few of the most important of the data obtained by the experiments of the Forest Branch of Munich University, conducted by Dr. Kast, lecturer on Forestry, who has kindly permitted me to make free use of his investigations on the subject.* As previously stated, although practically conclusive, they are still open to the scientific or academic objection that they fail to yield comparisons with actual measurements made on forest crops of absolutely similar nature growing on soils and situations also absolutely similar in quality and physical and climatic conditions, but differing only in never having been underplanted or never having had any artificial underwood formed below them.

The practical conclusions which it appears justifiable to deduce from these three series of carefully-made measurements may now be stated.

Practical Conclusions deducible from the Munich Investigations.

When forests of light-demanding species are underplanted, and the underwood begins to form close canopy, the effect is to produce a simultaneous diminution of the breadth of the annual rings in the basal portion of the stem, but to a much less extent, or not at all, in the upper portions of the bole, and without always diminishing the total annual increment on the tree. Wherever any considerable diminution of annual increment takes place in individual stems, it is probably due to re-formation of close canopy after thinning or partial clearance, in consequence of the full development and assimilative activity of the coronal foliage being interfered with.

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* "*Ueber den Unterbau und seine wirthschaftliche Bedeutung,*" 1889.

Runnebaum's experiments confirmed, so far as the Scots pine is concerned, Professor R. Hartig's theory that better and heavier timber is produced when there is underwood than when the soil is unprotected; but, as already explained, the other experiments could not yield final or academically satisfactory results. So much could, however, in a general way be deduced that, though favourable in other physical respects, undergrowth does not, as was generally accepted, directly stimulate to greater annual increment, owing to its withdrawing a portion of the nutrient salts from the soil. But the quantity of nutrients thus tapped is very inconsiderable, and does not at all justify the outcry of the opponents of underplanting, more especially on the better classes of soil. Their argument that, when thinnings or partial clearances are made, the spontaneous growth of grasses and weeds restores annually to the soil the nutrients taken from it, overlooks the fact proved by Vonhausen* that a soil covering of grass withdraws about four to five times as many nutrient salts as are utilised by beech undergrowth, and that as the humus formed by such soil-covering is almost entirely consumed by the superficial growth of weeds, the total of nutrients requisite for the maintenance of the annual development of the soil-covering is practically withdrawn from the possibility of being utilised by the timber crop,—whilst in comparison with that the quantity annually withdrawn by the underwood is inconsiderable, or at any rate so very much smaller as hardly to be practically taken in account, in the case of soils above the average, so far as concerns the further development of the standards. For the poorer classes of soils, however, it may possibly make its influence felt when the underwood is dense; but this will be more than counterbalanced by the larger increment which will follow thinnings or partial clearances in such cases in comparison with similar measures of tending carried out on tracts unprovided with undergrowth, in consequence of the greater supplies of dead foliage available for decomposition under the stronger action of light, air, and warmth. That the underwood can under certain circumstances make higher demands on the nutritive capacity of the soil than are preferred by the standards is of course self-evident, for it would be useless to attempt to underplant pine woods with beech on the poorer classes of sandy soil.

Next to the influence exerted on the total annual increment comes the question of the quality of the timber produced. This

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* "*Allgemeine Forst-und Jagd-Zeitung*," 1872, page 1.

is mainly influenced by a high form-factor, by freedom from branches and knots, by a large proportion of heartwood to sapwood, and finally by the height of the specific gravity, as for any mature samples of one and the same species of timber (in an equal stage of seasoning) it is incontrovertible that the heaviest is the most durable.*

The specific weight of any kind of timber *per se* is directly dependent on the proportion which the hard, dense, heavy zone formed during the hot weeks of summer bears to the lighter porous spring zone in the annual ring. The longer that activity of vegetation is delayed in spring, and the more it is forced into the warmer weather of summer, the denser, heavier, and technically preferable will be the timber produced; and as the practical effect of the underwood is to maintain the soil cool in spring by reason of the mechanical hindrance it offers to insolation and consequent direct heating of the ground, it delays, with favourable results for the quality of the timber to be formed, the annual commeneement of vegetation for at least a fortnight. For timber crops treated under the method of partial clearance this is of very great importance, as otherwise the approximate isolation of the standards would directly lead to the production of a poorer quality (although larger quantity) of timber than previous to the thinning out or partial clearance.

That the underwood is also of practical utility in clearing the lower branches from the stem hardly needs any demonstration. As it gradually grows up into the lower portions of the crowns it not only suppresses the foliage of the lower branches that can still maintain a struggling existence under the partial shade of the crowns, but otherwise aids mechanically in breaking off dead branches; and by maintaining the soil cool and moist it also assists materially in hastening their decomposition. This function of the undergrowth is, however, not of the first importance; for by the time it grows up into the lower crowns the natural thinning of the lower branches in normally developed forests should practically have already been completed.

From the experiments it seems warrantable to conclude that the older the underwood and the higher up it reaches into the lower portion of the crown, the greater is its influence in improving the form-factor and the consequent utility and technical and financial value of the stem; but these advantages are counterbalanced by a general reduction in the

* See Gayer's "*Forstbenutzung*," 7th edition, 1888, page 66.

annual productive capacity of the tree if the undergrowth be allowed to grow up high enough to interfere so far with the normal development of the crown of the standard trees as to cause partial suppression.

Concerning the natural laws which govern the quantitative relation of heartwood to sapwood practically nothing is yet known, though Runnebaum and others have found that pine standards with beech underwood show a larger proportion of heartwood than the trees grown in pure forests of pine. As, however, the same holds good for mixed forests of pine, spruce, beech, &c., there can be no justification for assuming that underplanting specially favours an increased production of heartwood or lessens the period of semi-activity which the older sapwood has to live through before attaining its highest maturity as duramen.

But the greatest ultimate importance of the undergrowth is undoubtedly to be looked for in the influence which it exerts on the soil, not only physically and immediately, but also throughout long subsequent periods, in consequence of the humus formed by the fallen leaves modifying all the physical properties of any given ordinary soil, and increasing and returning to it in a convenient, easily assimilated, soluble form the previously consumed supplies of nutrient salts. These physical and immediate influences of the undergrowth are everywhere visible in the maintenance of the soil against insolation, in the preservation of the soil-moisture, in the annual fall of leaves and its retention against being blown away, in fixation of the soil on hillsides, and in the slight but gradual assistance afforded by the humus towards effecting the further decomposition of the mineral layers and a consequent enrichment of the soil.

It is true that enormous quantities of moisture are transpired through beech leaves, even when forming undergrowth and in the enjoyment of but a limited supply of sunshine and light, and also that during rainfall a large percentage of the precipitations is caught up by the leaves and branches without reaching the ground; but the importance attached thereto by the opponents of underplanting seems hardly justifiable in the face of the fact that, without a layer of humus or moss, the surface-soil is little able to hold the moisture received as rainfall, whilst the evaporation caused by insolation and by the free play of winds must also be factors of enormous potentiality. As a matter of practical result, Ramann found* that, in the areas

* "*Zeitschrift für Forst-und Jagdwesen,*" 1885, page 172.

experimented on by Runnebaum, from the middle of May till the end of August there was always more moisture immediately underlying the humus in the pine forest underplanted with beech than in the pure pine woods; but below that down to a depth of 2 ft. the soil was moister in the former for the first half of the time, and drier throughout the second half, whilst the layers at about 28 to 32 inches below the surface were always moister in the pure pine woods. The explanation he gave was that in pure pine forests the spontaneous growth of grass, heather, &c., exhausted the superficial supplies of moisture to a greater extent than the beech underwood, whilst the middle layer at about 20 to 24 inches had to furnish supplies to both beech and pine, and that in the pure forest the deeper layer received larger supplies of moisture from the surface after the grasses had completed their development than could be the case where the beech undergrowth covered the soil. Wollny also obtained similar results in independent experiments conducted in Austria, which may briefly be summarised as follows* :—

1. That the quantity of moisture under a soil-covering of living plants is always less during the period of active vegetation than at a similar depth on naked soil, in consequence of transpiration through the foliage, and that this influence is traceable even down to the lower layers.
2. That the quantity found is less, the denser the plants stand, without being inversely proportional to the density.
3. That a soil-covering of dead growth or leaves, up to two inches in thickness, permits of better percolation of moisture from the surface-soil towards the lower layers than the naked soil seems to do.

These investigations, taken in conjunction with Ebermayer's conclusion† that forest soil was moister than similar soil in the open only in the upper layers, but was always drier in those pervaded by the roots, point to the correctness of Ramann's deductions.

The effects of underplanting with beech, hornbeam, or silver fir, which have all got a somewhat similar heart-shaped and moderately-reaching root-system, will be practically about the same; but in the case of the shallow-rooting spruce some modifications of the effects should be noticeable.

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* Wollny's "*Forschungen auf dem Gebiete der Agricultur-Physik,*" Vol. X., page 261.

† "*Die Physicalischen Einwirkungen des Waldes auf Luft und Boden,*" 1873, pp. 218–232.

In woods underplanted with spruce the upper layer of soil will still not contain more moisture than in pure forests, as the shallow root-system will draw its chief supplies of water from the soil lying within about 1 to 1½ feet from the surface, whilst below that the quantity of moisture should be about the same, at any rate during the first half of the annual period of vegetation. Owing, however, to the great density of spruce undergrowth, a considerable proportion of the atmospheric precipitations will be intercepted without ever having any chance of percolating through to the lower soil, so that the deeper layers may in general have less moisture than is to be found in similar soils bearing pure forests without underwood. As the foliage of spruce and silver fir is retained throughout the whole year, this not only intercepts a larger proportion of the precipitations during the non-active period, but also requires water for transpiration through the needles; hence, throughout the period during which broad-leaved deciduous undergrowth remains defoliated, the soil under the latter should, *cet. par.*, show larger supplies of moisture than soils bearing coniferous underwood.

It stands to reason that a dense undergrowth throughout a whole forest will withdraw larger supplies of moisture from the soil than one forming merely a loose canopy; and in consequence of this, it may perhaps be found to be of the greatest practical advantage to underplant in groups and patches wherever there is no good soil-covering of dead foliage or moss, as such partial underplanting will probably exert a sufficient influence in protecting the rest of the soil from the bad results of insolation, and in particular from the drying-up effects of winds. And although the former idea, that soils with a covering of underwood were always moister than those without, has not on investigation shown itself to be unconditionally correct, yet the importance of the retention of the fallen leaves, and the prevention of their being blown away by the wind, has in no way been overrated. But to serve this latter purpose something more is necessary than a thickly-foliaged outer fringe or belt along the edges of the forest, unless the compartments are very small and the soil is practically level, though even then the object in view is more safely attained by means of underwood.

It is a practical fact, hardly necessary of any elaborate demonstration or proof, that the more valuable assortments of oak and pine cannot be profitably* produced merely by strong

* See essay "*On the Selection of Species of Trees for Woodland Crops, and on the Choice of the Method of Treatment*, &c.," page 27.

thinnings out and prolongation of the period of rotation, as for their full normal development they demand a larger growing-space for the expansion of their crowns than can be given in pure forests without entailing serious interruption of the canopy, and consequent exposure of the soil to the deteriorating effects of insolation and exhausting winds. Strong thinnings or partial clearance about the 60th to 80th year for oak, or the 30th to 40th year for pine, when (according to the soil and situation) their main growth in height has culminated, and simultaneous underplanting or sowing of the species of shade-bearing trees best adapted for the particular soil, are the only advisable, rational, and remunerative method of stimulating the standards to further active production of good annual increment. It is not denied that the increment will be stimulated by the mere enlargement of the growing-space of the individual trees; but it is maintained, and in the foregoing seems to have been satisfactorily proved, that such enhanced increment on the individual trees must be dearly purchased at the cost of the subsequent deterioration of the productive capacity of the soil and diminution of the annual increment per acre, not to mention the higher technical and monetary value of the timber when the boles are not much inclined to taper.

Up to the present the underwood has been considered solely with reference to its influence on the later growth and development of the light-demanding standards; but it is also worthy of some special consideration on its own account. Even though all the standards be healthy and of normal appearance at the time of thinning and underplanting, further clearance to a greater or less extent is usually necessary before the utilisation of the whole crop is contemplated; and when there is no underwood, this simply means that on such places the soil is either not utilised at all, or not utilised to its full advantage. Where, however, underwood exists, it can grow up in the blanks to form part of the crop to be finally harvested. In such cases beech and hornbeam will yield less remunerative results than spruce or silver fir; for although, in general, under the shade of the standards, the latter will hardly develop into the better-paid assortments of timber, yet, thanks to the limited growing-space that suffices for the normal development of their crowns, they can of themselves—apart from their beneficial and remunerative influence on the main crop—often yield a good return for the initial costs of underplanting, and a moderate rental for the sub-tenancy of the soil they occupy.

With the maturity of the standard crop the underwood has done its duty, and can either be cleared away for the purpose of reproducing the standards naturally from the seed shed, or be retained for some time longer and treated as high forest, at any rate in groups or patches that show good development and give promise of a fair outturn in timber. Generally throughout Britain, however, where financial principles must mainly guide the landed proprietors in forest matters, and where there is a comparatively small and not very remunerative market for firewood, the clearance of the underwood. will precede the reproduction and utilisation of the standard crop. For the underplanting of the deciduous, light-demanding species of our forest trees—oak, ash, maple, and sycamore—beech, and on moister localities hornbeam yield better results on the whole than spruce or silver fir, as they accommodate themselves more to the natural development and habit of growth of the standards. For larch and pine woods, on the other hand, spruce, or on the better classes of soil, and in mild, sunny localities, Douglas, Nordmann's, or silver fir, naturally conform better to the habit of growth of these standard species, though underplanting with beech or hornbeam is still more decidedly advisable wherever the conditions of soil and situation render it possible, owing to the very advantageous influence the broad-leaved species exert in minimising the effects of damage done by insect enemies. In this latter respect their influence is somewhat similar to that of mixed forests, but less strongly marked; it becomes the greater, the more the underwood is able to extend upwards towards the lower portions of the crowns of the standards, and thus form, as it were, an integral portion of the leaf canopy.

But the choice of the species to be used for underplanting is dependent for the most part on considerations as to soil and situation. Without referring to special cases like the growth of alder as coppice under essentially light-demanding species on moist, fertile, rather marshy soils, it is practically limited to the four shade-bearing species, beech, hornbeam, spruce, and silver fir. Of these spruce is certainly most moderate in its demands, and it has another recommendation in deriving its supplies of nutrients chiefly from the upper layer of soil not tapped by the deeper-rooted species, oak and pine; the other three species not only make greater demands on the mineral strength of the soil, but also through their deeper root-systems tend to come more in competition with the standards with regard to the withdrawal of the nutrients held in solution in the middle layers of the soil. Speaking generally, however, broad-leaved species certainly

deserve the preference if underplanting takes place simply with a view to the protection and improvement of the soil; whilst a mixture of conifers and broad-leaved species recommends itself wherever it is desired to obtain a crop of fairly marketable stems along with the mature standards. That the greatest improvement in the soil takes place when beech is the underwood is incontestible; but in consequence of its comparatively high demands on potash and phosphoric acid it cannot be used on the poorer classes of soil, and when growing under-oak in damp localities exposed to late frosts it suffers considerably more than hornbeam in consequence of its flush of spring leaves coming about a fortnight earlier than those of the standards. Where a choice remains open only between spruce and silver fir, or for admixture of these with the beech or hornbeam, the silver fir in general deserves the preference, notwithstanding its deeper root-system and greater claims on mineral strength of soil, for it bears shade better on the whole, is more favourable to the formation of humus, and does not close the soil so much to the circulation of air, to the reception of atmospheric precipitations, and to the percolation of the surface-moisture down through the upper layers towards the subsoil. For the underplanting of oaks, spruce is not to be recommended, as it is apt to interfere greatly with the functions of the crown later on; for oak-soils the beech, and on moist parts the hornbeam, should form the bulk of the underwood, with silver fir mixed in patches where there seems any chance of its ultimately being likely to develop into good marketable dimensions. The underplanting of oak with spruce has been practically condemned by most of the eminent sylviculturists in Germany. There are several reasons for this, one of them being that, by intercepting and utilising for its own benefit a large proportion of the atmospheric precipitations, it induces "*stag-headedness*," owing to insufficient supplies of moisture reaching the lower layers of soil; but this disease is often also due to injudicious thinning or partial clearance on soils below the average in quality, and naturally somewhat deficient in moisture, when the evil is, of course, aggravated by the choice of spruce as underwood. Although Weymouth and black or Austrian pines bear more shade than Scots pine, their capacity in this respect is hardly great enough to admit of their being utilised as underwood; much better results are promised by the Douglas and Nordmann's firs, which closely resemble the silver fir in many respects.

The opinion was formerly general among sylviculturists that the full advantages of underplanting were only obtainable when the whole area was under cover; but although the fullest returns

from dead foliage can undoubtedly be thus secured, other points of view seem to indicate that partial underplanting can also attain desirable results, whilst at the same time obviating certain drawbacks relative to the too extensive demands of a full, dense undergrowth on the moisture of the soil. For such partial underplanting in patches or small groups the advantages claimed are that by occupying only a portion of the soil it competes to a much less degree with the standards in making demands on nutrients, a matter which is of the greater importance, the poorer the soil is; that whilst withdrawing smaller supplies of moisture from the ground it permits a larger proportion of the atmospheric precipitations to reach the soil directly, and at the same time affords the necessary protection, both mechanically and otherwise indirectly, against the rapid evaporation caused by sun and wind; that it stimulates the decomposition of the fallen leaves and needles by favouring the freer play of the necessary factors, warmth, moisture, and atmospheric oxygen, and prevents the accumulation of an unproductive, undecomposed layer of foliage, such as may often be noticed in the case of dense underwood of spruce especially; that it offers the best means of forming mixed undergrowth on all places where soil, situation, or standards require different species from the rest of the area, or any special treatment of the underwood chosen; and that, finally, it costs only a proportional amount of the outlay that the planting up or sowing of the whole area would entail.

Recapitulation.

To recapitulate briefly the results of the Munich experiments, it has not yet been shown that the undergrowth exerts any direct and immediate influence on the increment of the light-demanding standards, but it undoubtedly does improve the shape of the bole, and consequently enhances its financial and technical value, and also improves the quality of the timber, at any rate in the case of the light-demanding conifers. Again, by increasing the quantity of fallen leaves and needles, and preventing them from being blown away by winds, it essentially favours the production and direct increase of humus, so that it materially affects the physical properties of the soil and stimulates its productive capacity.

Oak, larch, and pine are the species extensively grown in pure forest which stand most in need of underplanting when once they have completed their main growth in height and

begin to make larger demands on growing-space; the other light-demanding species, like ash, elm, maple, and sycamore, should less frequently be grown in pure forest than simply as patches in mixed woods, where a ruling species, preferably the beech, protects the soil against deterioration. Shade-bearing species require no undergrowth. Unless maintained in close canopy they tend to branch development and consequent reduction of the form-factor of the bole, with diminished monetary and technical value; moreover, it is only on the very best qualities of soil that beech, spruce, or silver fir can thrive for any length of time under the dense shade of parent standards forming anything like a full canopy.

Whether the underwood should be formed by sowing or planting depends in each case on local circumstances. Sowing is in the majority of cases much cheaper, but it takes longer to attain the object in view. Planting can be easily carried out, wherever practicable, with seedlings from neighbouring woods or with two to three-year-old seedlings or transplants from temporary nurseries, and should not amount to more than about 15*s.* per acre if put out from $3\frac{1}{2} \times 3\frac{1}{2}$ to 4×4 feet apart by means of notching. But even should the costs of underplanting be higher locally, the advantages of the method are still cheaply obtained where the intention is to produce the most satisfactory monetary returns from pure forests of oak, larch, or pine that are unable of themselves to protect the soil against deterioration, but which it is not desirable to clear away yet for the formation of other crops of timber. Many an oak grove in England, and many a larch and pine tract in Scotland, would yield far more satisfactory returns from every point of view—financially, sylviculturally, technically, and æsthetically—if due measures were taken for the protection and improvement of the productive capacity of the soil by means of underplanting after thinning or slight clearance, and treatment thereafter in accordance with the rational principles of the science of forestry.